

Recent Developments in Natural Fiber as Reinforcement in Polymeric Composites: A Review

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ABSTRACT

In recent years, research on replacing manufactured fibers such as glass fibers with natural fibers as reinforcement in polymeric composites has increased rapidly. Natural fibers are an important by-product with many advantages such as abundance, biodegradability, flexibility during processing, minimal health hazards, relatively high tensile and flexural modulus, low density, low cost, and recyclability. Although natural fibers possess many advantages, as mentioned above, they suffer from some drawbacks while used in polymer matrix composites. Therefore, it is necessary to modify the fiber surface by suitable chemical treatment. The fibers had to be treated with sodium hydroxide to improve the interfacial adhesion between the fiber and the matrix, which optimized the mechanical and physical properties of these composites. Maleic anhydride was added to the composites to improve fiber composite compatibility and also to improve the properties of the composites. The main objective of this review, study the different properties of a cost-effective and eco-friendly composite material. This material consisting of natural fiber as the reinforcing component and polymeric materials as the matrix. In this review, the effects of natural fiber content, alkali treatment, and the addition of coupling agent on the composite properties were performed.

Keywords: Natural fiber composites, Mechanical properties, Polymeric matrix, Physical properties, Chemical treatment.

Introduction

Polymer Matrix Composites (PMC) is the most commonly used composite among various composites due to its many advantages, such as low cost, light weight, and can be processed at low temperature [1,2]. PMCs have two types of polymer that have been used as matrices. These are thermoplastics and thermosetting polymer [3-5]. Thermoplastic materials currently dominate as matrices for bio fibers; the most commonly used thermoplastics for this purpose are polypropylene (PP), polyethylene, and polyvinyl chloride (PVC); while phenolic, epoxy, and polyester resins are the most commonly used thermosetting matrices [6-8].

Natural fibers have many advantages such as its abundance, low cost, biodegradability, low density, easy availability, environmentally friendly nature, good mechanical properties, recyclability, which makes them highly suitable for use as an alternative to conventional glass and carbon fibers in the production of thermoplastic materials [9-12].

As a result, they are used as a reinforcement in fiber-reinforced plastics and used in a variety of applications such as bumpers, automotive structural components such as doors, roofs, and covers, consumer goods, machine parts, medical equipment, and packaging and storage materials, as well as furniture articles such as office chairs and door panels [13-15]. Figure 1 shows natural fiber reinforced composites market volume share (%), by end-user industry, global (2021).

Normally, natural fiber polymer composites are fabricated using traditional manufacturing techniques designed for conventional fiber-reinforced polymer composites and thermoplastics. These techniques include resin transfer molding, vacuum infusion, compression molding, direct extrusion, compounding, and injection molding [16].

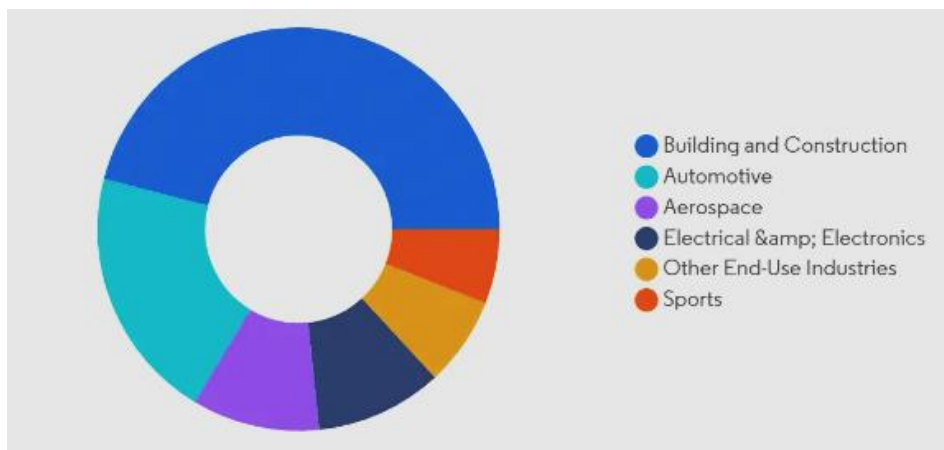


Fig.1. Natural fiber reinforced composites market volume share (%), by end-user industry, global (2021)

Several types of natural fibers and their derivatives, such as coir, hemp, banana, Borassus, sisal, green coconut, jute, Agave leaf fibers, tamarind, flax, kapok, kenaf, Bagasse has been studied for used as possible reinforcements in polymer composites [17-28].

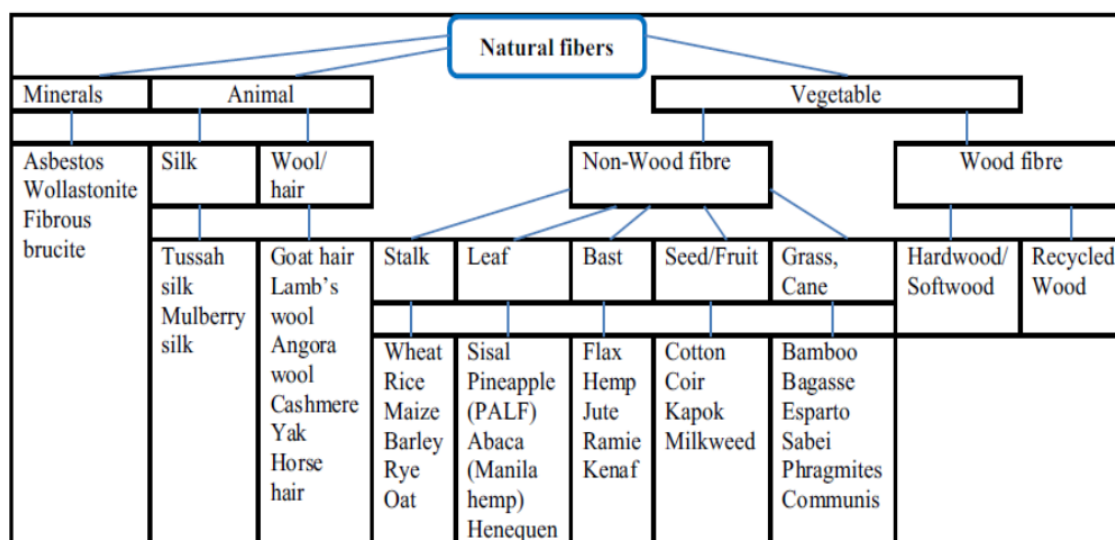


Fig.2. Classification of natural fibres [29]

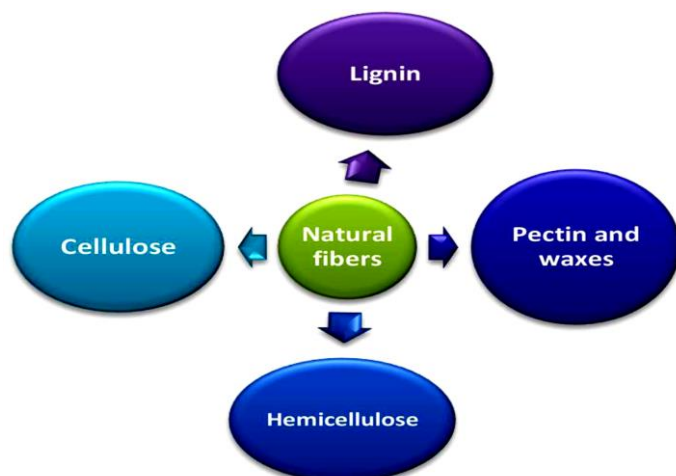


Fig.3. Constituents of plant fibers [33]

An overview of the classification of natural fibres from Mohanty et al. [29] is given in Fig.2. These fibers mainly consist of cellulose, hemicelluloses, lignin, pectin, waxes, and water-soluble substances as shown in Fig.3 [30-33]. This review provides an overview of previous research on the rheological and thermal properties, chemical resistance, and mechanical characteristics of polymers reinforced with several natural fibers. Additionally, the effect of ultraviolet radiation on the morphology of the composites. Also, the influence of adding coupling agents on the properties of the natural fiber composites.

The Rheological and Mechanical Properties

Melt flow index (MFI) is defined as the weight of the polymer (g) extruded in 10min through a capillary of specific diameter and length by pressure applied through dead weight under prescribed temperature conditions according to ASTM D1238. The test conditions include temperatures between 180°C and 220°C and different applied dead loads from 0.325 to 21.6 kg giving pressures from 0.46 to 30.4 kg/cm².

Li et al. [34] manufactured a composite of flax fiber as the reinforcing component and high-density polyethylene (HDPE) as the matrix. They studied the rheological and mechanical properties such as tensile and flexural properties of composites after injection molding. The results showed that the increase in the fiber content increased both the tensile and flexural strength. By contrast, the MFI value decreased as the proportion of flax fiber increased. Ramaraj [35] examined the possibility of using SCB waste as a reinforcing filler in the thermoplastic polymer matrix by preparing SCB reinforced polypropylene (PP) composites. These specimens were tested for determining properties such as tensile, flexural, impact strengths, and heat deflection temperature (HDT), melt flow index. Results showed that all properties increased with increasing in filler loading. However, the tensile strength and elongation decreased. In the case of MFI, the addition of SCB reduces MFI. The reduction in melt flow is as expected because SCB does not melt, and also, it is in fibrous nature. Tasdemir et al. [36] produced wood-plastic composites (WPC) from a mixture of wood fiber and thermoplastic PP and LDPE through an extrusion process. They examined the tensile strength, the modulus of elasticity, % elongation, hardness, Izod impact strength, and MFI. The results showed that the elastic modules and hardness improvements with increasing the fiber content. In some of the mechanical properties of the composites (such as elastic modules, hardness, and HDT), without severely affecting other properties (such as tensile strength, elongation-at-break, and toughness). The results also show that the MFI decreased with an increase in wood flour concentration.

Poletto [37] studied the melt rheological properties and the activation energy to flow of wood flour reinforced PP composites by using a melt flow indexer in a temperature range of 180-220°C. The results showed that the addition of wood flour into the polymer matrix reduces the melt flow index, probably due to restrictions imposed by the wood particles to polymer flow. The results also showed that the viscosity of the composites increased when wood flour was added to the composite formulations because of the restriction to flow imposed by the fibers. The increase in temperature causes a reduction in the melt viscosity.

Alam et al. [38] fabricated polylactide (PLA) composites reinforced with differently treated fibers. Glass transition temperature, crystal melting temperature, decomposition temperature, melt flow index, density, and mechanical properties (tensile strength, tensile modulus, and impact strength) of the fabricated PLA composites reinforced with

differently treated fibers are examined. The results showed that the treated fibers reinforced composites exhibit an increase in mechanical properties, such as tensile strength, tensile modulus, and impact strength along with melt flow index consequently. Furthermore, FTIR and SEM have provided clear evidence of more adhesion of PLA with treated fibers than with untreated ones. Increased thermal stability in treated composites is observed.

Thermal Degradation

Vidyashri et al. [39] used sugarcane bagasse fiber to reinforce an epoxy polymer to form natural fiber-reinforced composites. They chemically treated raw fiber to improve its compatibility and adhesion with the epoxy polymer. The thermal properties were evaluated by Thermogravimetric Analysis (TGA). The results revealed that treated fibers show improved thermal properties. Reddy et al. [40] investigated the effect of alkali treatment on the thermal degradation, and surface changes of Napier grass fibers. The fibers were mercerized with sodium hydroxide to improve the fiber and matrix compatibility. The results showed that the thermal stability of the fibers were found to increase by alkali treatment. The morphology of the fibers after alkali treatment indicated roughening of the surface. Neto et al. [41] used sugarcane bagasse fibers as a filler in composites having recycled high-density polyethylene (RHDPE) as a matrix. They chemically modified the surface of the bagasse due to the poor interaction between the fiber surface and the matrix. They analyzed materials by SEM, TGA, and evaluated the mechanical properties. They found that the chemical modification of sugarcane bagasse increased the compatibility between matrix and reinforcement. The results also showed that the mechanical properties of the composite were improved. Additionally, there is an enhancement in the thermal stability of the lignocellulosic structure of the fiber.

Essabir et al. [42] prepared HDPE composites reinforced with treated bio-filler from Argan-Nut Shell (ANS) at different filler contents. They investigated the thermal stability by TGA, and rheological testing. The results of thermal analysis revealed that the incorporation of bio-filler in polymer results in a decrease in decomposition temperatures.

Mile'o et al. [43] attempted to obtain and evaluate the thermal properties of castor oil polyurethane composites reinforced with lignin and cellulose from sugarcane bagasse. Sugarcane bagasse was pretreated and then delignified. The results showed that the presence of lignin or cellulose fibers in the polyurethane matrix decreases the thermal stability compared with the neat matrix. Prasad et al. [44] investigated the effect of coir fiber addition and the banana fiber in LDPE to develop cost-effective and high-performance composite material. They analyzed the effect of hybridization through the mechanical properties (tensile, flexural, and impact), thermal stability, morphological behavior, and water absorption behavior. The results showed that incorporating coir fiber into the banana fiber composites of up to 50% by weight led to enhancement of the mechanical properties and thermal stability and reduced the water absorption capacity of the banana fiber/LDPE composites.

Arrakhiz et al. [45] studied the effect of adding fibers into polymer matrix through examining the thermal and mechanical properties of Doum-fibers reinforcing LDPE composite. They found that the mechanical properties of composites were enhanced. The results also showed that Young's modulus was improved by 145% compared to the neat polymer at 30 wt.% fiber loading. The flexural modulus also increased by 135% at 20 wt.% fiber loading. In addition, the torsional modulus was increased by 97% at 0.1 Hz. Finally, the results showed a slight decrease in the

Thermal properties by increasing the added Doum. Oladele et al. [46] evaluated the effect of mercerization of SCB fiber by sodium hydroxide on the mechanical and thermal properties of the composites. Samples were characterized for tensile, flexural, and thermal properties. The results showed that the mercerized composites exhibited improved mechanical properties than the unmercerized composite and control sample. Additionally, TGA/DTG analysis revealed that the mercerized composites were more thermally stable than other samples. Mulinari et al. [47] evaluated the mechanical and thermal properties of LDPE composites reinforced with fibers from Australian King Palm fibers. They also prepared tensile, flexural, and impact specimens for the evaluation of mechanical properties. The composites were analyzed through SEM micrographs of fractured surfaces and thermal analysis. The results indicated that the reinforcement decreased the thermal stability of the composites but caused an increase in the mechanical properties of the composites. El-Fattah et al. [48] prepared HDPE/SCB fiber composites by compression molding. They studied the effects of the SCB fibers content and the addition of compatibilizing agent maleated polyethylene on the composite properties. The scanning electron micrographs of the compatibilized composites showed clear evidence of good interfacial adhesion between the fiber surface and the polymer matrix. The tensile tests revealed that the compatibilized composites provide better tensile strength and modulus than the uncompatibilized composites. The thermal stability, elongation at break and the impact strength for the composites decreased.

Hossain et al. [49] studied the effect of chemical treatment on the tensile, thermal, and morphological properties of single sugarcane fiber bundles. Surface modification of fiber bundles was accomplished by performing alkali treatment and neutralizing by acetic acid solution. The results showed that the tensile strength and modulus for the treated fiber bundles were better than those of untreated ones. It was found that the Fracture morphology of the treated fiber bundles is cleaner and rougher fracture surface compared to those of untreated ones. The results also revealed that the treated composites were more stable than the untreated ones. Vega-Baudrit et al. [50] tried to prepare a composite based on bagasse fiber and polyurethanes. They characterized the composite according to its bulk density, thermal (TGA), and mechanical (compression modulus) properties.

The results showed that the composite PUF sample with 10% sugarcane fiber added as reinforcement had the lowest bulk density. Also, its TGA thermal analysis showed a general trend towards reducing both the initial temperature of decomposition, as well as the temperature at the maximum rate of degradation, compared to composite without fiber added. Finally, its mechanical properties showed a maximum value for both efforts to compression strength and modulus. Bertoti et al. [51] tried to achieve chemical modification of SCB fiber by the mercerization reaction. The results showed that the fiber length and diameter were reduced after the reaction. The thermal stability was measured by TGA and differential scanning calorimetry (DSC). The results showed that the thermal stability increased after mercerization.

Chemical Resistance Properties

Gupta [52] examined the effect of fiber content on the chemical resistance and water absorption of composites to find the industrial suitability of the composites. The epoxy matrix is reinforced with bamboo fiber and synthesized by the hand layup technique. They used scanning electron micrographs of composites for qualitative evaluation of the interfacial properties of bamboo/epoxy composites. The results indicated that chemical resistance decreases

with increasing fiber content. Water absorption increases with the increase in fiber fraction. Jawaaid et al. [53] fabricated Hybrid composites of an epoxy matrix reinforced with oil palm empty fruit bunch (EFB) and jute fiber mats by hand lay-up technique. They evaluated the physical and chemical resistance properties of hybrid composites. They found that the physical and chemical resistance properties of hybrid composites were enhanced by increasing the jute fiber loading in hybrid composites. The results also showed that the void content of hybrid composites decreases with increasing jute fiber loading because jute fibers showed better fiber/matrix interface bonding. The performance of hybrid composites towards chemical reagents improved with an increase in jute fiber loading compared to the EFB composite. The combination of oil palm EFB/jute fibers with epoxy matrix produced hybrid biocomposites material that is competitive to synthetic composites. John and Naidu [54] developed the unsaturated polyester resin-based sisal/glass hybrid composites using the hand lay-up technique. They performed chemical resistance tests of these hybrid composites. The hybrid samples and the matrix have been tested for various acids, alkalis, and solvents. The results showed that the developed hybrid composites are resistant to all the tested chemicals except carbon tetrachloride.

Effects of weathering on degradation (The effect of ultraviolet radiation)

Ordinary light is a mixture of light of many different colors. A beam of sunlight passing through a prism fans out into a band of colors. At one end of this band is red, followed by orange, yellow, green, blue, and violet, each color blending into the next. This particular sequence is called the visible range of the electromagnetic spectrum because it is the only range of the spectrum that humans can see with the unaided eye. Visible light itself is only a small part of a much larger spectrum of electromagnetic radiation. The distribution of radiation depending on wavelength (the so-called spectrum of emission) covers ranges (or bands) called visible (VIS) (between 400 and 720 nm), infrared (IR) (wavelength longer than 720 nm), and ultraviolet (UV). Ultraviolet radiation is defined as electromagnetic radiation having wavelengths within the range of 200–400 nm that is shorter than the visible light but longer than the X-rays, and it is divided into three different bands. UVC corresponds to wavelengths from 200 to 280 nm that are considered to be the most harmful, but they do not reach the Earth's surface because they are completely filtered by the ozone layer in the atmosphere., UVB corresponds to wavelengths in the range from 280 to 315 nm and has a medium wave length. Only its part passes through the atmosphere., and UVA corresponds to wavelengths from 315 nm to the visible lower limit (400 nm), which have a relatively long wave length and represent close to 95% of the UV rays that make it to the Earth's surface [55]. Natural fiber composites exposed outdoor with direct sunlight are subjected to radiation which breaks the covalent bonds in organic polymers causing yellowing, color fading, weight loss, surface roughening, mechanical property deterioration, and embrittlement with more reduction in wetter conditions [56]. Articles of polymeric materials are exposed to light outside, leading to their aging, which is associated with polymer chain rupture by the action of UV light with a wavelength of 300-400 nm [57].

Fechine et al. [58] investigated the surface characterization of photo degraded poly (ethylene terephthalate). Films obtained by bi-axial extrusion were exposed in a laboratory weathering chamber for up to 1100 h of irradiation. They tested the samples prepared with and without an ultraviolet (UV) absorber by FT-IR, UV-visible, and fluorescence spectroscopy. The results indicated that the unsterilized films are susceptible to the degradation effects causing a large deterioration, especially in surface layers. The presence of an ultraviolet light absorber

effectively reduced the formation of carboxyl end-groups at the surface as well as in the bulk of the films. In the case of samples with UV absorbers, the fluorescence data showed a barrier imposed by this additive in the formation of the monohydroxy-terephthalate. Scanning electron microscopy of fractured surfaces showed that film ductility is highly reduced after exposure.

Theiler et al. [56] investigated the effects of weathering exposure on unfilled and filled thermoplastic polyurethanes (TPU) materials under different humidity conditions. They used a weathering device with UV-A 340 nm lamps at a constant temperature of 40°C. The effects of environmental (UV and humidity condition) degradation on the mechanical properties and the surface analyses are characterized. The results reveal that the Photooxidative degradation of unfilled polymer leads to deterioration of physical and mechanical properties. Due to crosslinking, the stiffness of the material increases, reducing the friction coefficient of unfilled TPUs drastically. Boubakri et al. [57] investigated the effect of accelerated UV-aging radiations on the physical and mechanical properties of TPU material. They studied changes in mechanical properties, material structure, appearance, and morphology using scanning electron microscopy (SEM), tensile testing, abrasive wear tester, and differential scanning calorimetry (DSC). It was found there is a colorless appearance, yellower in the first stage of aging, and then turn to brown and therefore remained almost unchanged, and microcracks are formed on the UV-exposed surfaces. Lopez et al. [59] studied the effect of moisture, temperature, and UV light on the performance of natural-fiber-plastic composites (NFPC). They conducted short-term tests in the laboratory and long-term tests under natural exposure and measured changes in mechanical properties and color in composite samples. They measured the Chemical changes of the composite's materials by X-ray photoelectron spectroscopy to elucidate the mechanisms of chemical transformations on the material surface. The results indicated that the relative humidity had a greater effect on the modulus of rupture and the modulus of elasticity than temperature and UV exposure. The UV effect increased the lightness of the composite in short- and long-term tests. The X-ray photoelectron spectroscopy (XPS) analysis suggested that the UV absorber protected the composite.

Leão et al. [60] used ortho-terephthalic polyester resin as a matrix reinforced with two layers of unidirectional woven licuri fiber. They studied the influence of environmental degradation on morphology and fracture characteristics by microscopic analysis of the microstructure and mass loss, and mechanical properties. It was found that the licuri fiber reinforced plastics exhibited certain advantages in their responses to environmental aging. These advantages are evident in behavior related to photo-oxidation and microstructure degradation. Losses were recorded in the mechanical properties of the aged laminate when compared to the original condition; however, the structural integrity was little affected.

Rodrigues et al. [61] investigated the combined effects of humidity and UV on the mechanical properties of a hybrid composite comprising glass-E and curaua fibers reinforcing terephthalic polyester resin, so an accelerated environmental aging chamber was carried out. Mechanical properties were evaluated using tensile and three-point bending tests, along with analysis of fracture characteristics. Mass loss analysis of the specimens was also conducted during exposure in the chamber. A composite with only glass-E fiber was also tested and used as a basis for comparison. The hybrid composite exhibited mechanical properties similar to those containing only glass-E fiber in the original condition. After aging, there was a decrease in mechanical properties. Aging was more harmful

to the hybrid composite than the glass-E fiber composite. The new hybrid composite developed is intended for engineering applications as an alternative to glass fiber composites. Falk et al. [62] evaluated the effect of UV exposure on the fading of the HDPE and PP reinforced with (50% and 70% by weight) wood flour composites as well as the effect of weathering on the degradation of engineering properties by using An accelerated aging device. They examined the durability performance of natural fiber-thermoplastic composites intended for use in roofing applications. The results indicated that low variability in fading and mechanical properties.

Claude et al. [63] assessed the impact of photochemical modifications induced under UV irradiation upon the physical properties of BPAPC polymer. They measured the glass transition temperature and the Young modulus at a microscopic scale. The results exhibited that as aging time increased (longer irradiation times), oxidation of the polymer took place. This oxidative degradation leads to the formation of a cross-linked structure on the exposed surface, so the glass transition temperature and the Young modulus increased, whereas, in the bulk of the material, aging involves chain scissions characterized by a decreased glass transition temperature. Benini et al. [64] investigated the effect of accelerated weathering on the visual appearance and on mechanical properties of high impact polystyrene (HIPS) as well as HIPS reinforced with mercerized and bleached SCB fibers composites. After the accelerated weathering period of 900 h, under UV-B radiation, changes in mechanical properties are investigated by tensile tests. Materials fracture surfaces are investigated by scanning electron microscopy (SEM). The study showed that the exposure time was sufficient to change the visual appearance of HIPS as the composites. It was observed that composites reinforced with bleached fibers are less susceptible to accelerated weathering exposure than composites reinforced with mercerized fibers, which is explained by the higher amount of lignin present in mercerized fibers.

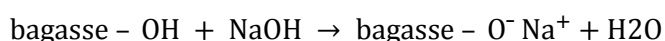
Fabiyi et al. [65] investigated the effects of outside and accelerated (xenon-arc and UVA) weathering on the visual appearance and chemical changes of wood plastic composite (WPC) formulations based on HDPE and PP. Colorimetry, scanning electron microscopy, and Fourier transforms infrared spectroscopy (FT-IR) were employed in this study. The results showed that for both outside and accelerated weathering, longer exposure time increased the degree of color change (and lightness), carbonyl concentrations, and wood loss on weathered WPC surfaces. HDPE-based WPC exhibited decreased lightning, carbonyl concentrations, and wood content loss when compared to PP-based WPC. Oxidation and degradation of wood lignin influenced WPC color changes (lightening) during weathering.

Butylina et al. [66] examined the effects of outdoor weathering on the properties of wood-PP composites with and without pigments. The weathering resulted in considerable color fading of the composites. Composites containing darker color pigments had better color stability. Scanning electron microscopy analysis revealed that surface cracks caused by weathering in a wood polypropylene composite having a higher polypropylene content were less abundant, and the deterioration of the surface layer was lower compared to composites containing less polymer. Beg and Pickering [67] studied combined moisture/ultraviolet (UV) weathering performance of 40 wt% unbleached and bleached Kraft wood fiber reinforced PP composites with 3wt% of a maleated polypropylene (MAPP) coupling agent. Composite mechanical properties were evaluated, before and after accelerated weathering for 1000 h, by tensile and impact testing. Scanning electron microscopy (SEM) was also carried out to assess the

changes occurring during accelerated weathering. Bleached fiber composites initially showed higher tensile and impact strengths. During accelerated weathering, both unbleached and bleached fiber composites reduced tensile strength and Young's modulus. The surfaces of samples exposed to the accelerated weathering environment were observed to change in the form of color fading and deposition of white chalky material.

Properties of Polymer Reinforced via Untreated and Treated Natural Fibers with/without Coupling Agent

several chemical treatments of the fibers can be used to increase the compatibility, thereby enhancing the performance of the composite [68]. Table 1 shows different chemical treatments and their effects [69]. One of the approaches to improve the inherent properties of natural reinforcements is the alkali treatment of the fibers. It is the simplest and cheapest method to modify natural fibers and is a commercial technology that consists of treating the fibers with a sodium hydroxide solution [27,30,70]. It increases surface roughness resulting in better mechanical interlocking, and It increases the amount of cellulose exposed on the fiber surface, thus increasing the number of possible reaction sites [71]. It removes the non-cellulose constituent in fibers such as lignin, wax, and oils, induces ionization of the hydroxyl groups of cellulose to alkoxide, and reduces the hydroxyl group content on the fiber's surface. It also enhances the surface roughness, rigidity, and hydrophobicity of the fiber, and consequently, the adhesion of the fibers with the polymer matrix increases [30]. And also to reduce it to its fibrous form [23].



A coupling agent is a compound that provides a chemical bond between two dissimilar materials, usually inorganic and organic. Maleic anhydride (MA) was also used to alter the flexibility of the natural fiber-reinforced thermoplastics composite, indicating that it acted as a compatibilizer at the matrix interface.

Table 1. Different chemical treatments and their effects [69]

Chemical Treatments	Functional Groups/ Coupling Agent	Specific Effects on Natural Fibers
Benzoylation treatment	Benzoyl chloride	Makes fibers hydrophobic
Peroxide treatment	Polyethylene	Improve the adhesion of fibers with a matrix
Sodium Chlorite treatment	Sodium Chlorite (NaClO ₂)	Remove moisture from fiber
Acrylation and acrylonitrile grafting	Acrylic Acid (CH ₂ — CHCOOH)	Bonding capacity and stress transfer of the interface increases
Oleoyl Chloride treatment	Oleoyl Chloride	Improves wettability and adhesion properties
Triazine treatment	Triazine (C ₃ H ₃ N ₃)	Improves the adhesion of the fibers
Permanganate treatment	Potassium Permanganate (KMnO ₄)	Improves the thermal stability of the fibers

The MA segments of the copolymer reacted with the hydroxyl groups (OH) on the fiber surface. They created a chemical bridge between reinforcement and the matrix that formed bonds with natural fibers, giving a compatibilization effect [68]. The result shows that the dispersion of bagasse fiber in the thermoplastic polymer matrix was improved after adding 3wt.% [72]. Akhtar et al. [15] studied the fabrication and characterization of untreated and treated kenaf/PP reinforced composites using the injection molding technique with different fiber loadings of treated and untreated kenaf composites. The results showed that the alkaline-treated kenaf composites exhibit better physical, morphological, and mechanical properties because of the compatibility of kenaf with PP. In addition, 40 wt.% kenaf fiber loading resulted in higher mechanical properties. Therefore, 40% kenaf/PP composites can be used in various applications such as automotive, sports, construction, animal bedding, and mass production industries.

Sullins et al. [73] studied the effects of material treatments on the mechanical behaviors of hemp fiber reinforced PP composites. They investigated the mechanical behaviors with different combinations of material treatment. 15 wt.% and 30 wt.% hemp fiber loadings are used in the composites with these material treatments. They found that the material treatments resulted in better mechanical properties compared to the composites without any treatment. Fahim et al. [74] investigated the potential usage of LDPE reinforced with different concentrations (2%, 5%, and 6% by weight) of treated rice straw. They used alkali and acidic treatments for rice straw. The removal of impurities and waxy substances from fiber surfaces avoids the creation of rougher topography after treatment and improves the quality of fiber. The results showed that the mechanical properties of the polymer composite had been improved compared to the polymer.

Acharya and Mishra [71] tried to utilize bagasse fiber to prepare a composite using epoxy resin. The fiber surface was modified by alkali treatment. They investigated the effect of fiber surface modification on the mechanical properties, such as the flexural strength of the composites. They concluded that alkali-treated bagasse/epoxy composites significantly improved the flexural strength of the composite. The SEM investigation also indicated that the surface modifications improved the fiber-matrix interaction. Cao et al. [75] prepared biodegradable composites reinforced with SCB fiber before and after alkali treatments and investigated the mechanical properties. They found that the mechanical properties of the composites made from alkali-treated fibers were better than untreated fibers. Approximately 13% improvement in tensile strength, 14% in flexural strength, and 30% in impact strength were found, respectively. SEM observations on the fracture surface of composites showed that the surface modification of the fiber occurred and improved fiber-matrix adhesion.

Mihaela et al. [76] used hemp fibers modified by alkali and alkali-silane treatment to reinforce a PP matrix modified with maleic anhydride grafted polypropylene (MAPP) and SEBS. They concluded that adding HF in PP modified with MAPP and SEBS has increased the tensile strength, modulus (by 45% and 230%), and impact strength. The HFs led to a significant increase of storage modulus, with about 100% at room temperature and about 200% at 120°C. Moreover, the onset degradation temperature increased with 51°C for HFs containing composites compared to neat PP. PP/HFs composites modified with MAPP and SEBS showed improved mechanical and thermal properties, being considered a viable alternative to PP/GF composites for injection molded parts in the automotive industry. Ganapathy et al. [77] investigated the suitability of cellulosic fiber extracted from the aerial

roots of the Banyan tree (ARBFs) as reinforcement in fiber-reinforced plastics. They studied the fundamental properties of ARBFs such as density, tensile strength, chemical composition, crystallinity index, crystalline size, thermal stability, maximum degradation temperature, and surface roughness. The chemical analysis results revealed that cellulose content was improved after the alkalization. Thermal analysis results confirmed the maximum degradation temperature (368 °C). The results of scanning electron microscopic and atomic force microscopic analysis exhibited that impurities and wax on the outer surface of the ARBFs were removed after the alkali treatment.

Subramonian et al. [78] studied the effect of reinforcing PP matrix with alkali-treated SCB with different Fiber loading. Composite samples were subjected to tensile, hardness, and flexural characterization. They concluded that composites with 30 wt.% of fiber loading registered maximum tensile strength, while 10wt% fiber loading registered the minimum. They revealed that hardness increased with increasing the amount of fiber. They also found that flexural strength and flexural modulus were greater than original polypropylene. Santhanam and Chandrasekaran [79] tried to utilize bagasse fiber to prepare a composite using epoxy resin. The fiber surface was modified by alkali treatment with 5% NaOH solution. They investigated the effect of fiber surface modification on mechanical properties. It was found that alkali-treated bagasse/epoxy composites significantly improved the flexural strength of the composite. An SEM investigation also indicated that the surface modifications improved the fiber-matrix interaction. Saini et al. [80] evaluated the effect of filler content, particle size, and alkali treatment of bagasse powder on the properties of PVC. The results revealed that the tensile strength, percent elongation at break, and impact strength of composites decreased. In contrast, stiffness, modulus, and hardness of the composites increased with increasing the amount of filler. The particle size had a large effect on the properties of composites gave better properties. Some improvement in properties was observed when treated bagasse powder was used as filler.

Habibi et al. [81] processed composite materials from the cotton stalk, rice straw, bagasse, and banana plant waste as natural lignocellulosic fibers using LDPE and acid stearic as a compatibilizer, or malleated low-density polyethylene. The tensile test was investigated. The results showed that better compatibility and enhanced mechanical properties were obtained using maleated LDPE as compatibilizer. Moubarik et al. [82] treated cellulose fibers from Moroccan SCB by alkaline treatment to eliminate hemicellulose and lignin. They also investigated the reinforcing capability of cellulose fibers extracted from sugar cane bagasse using LDPE as a matrix. They found that an enhancement in mechanical properties of composites was achieved as a result of a good interface adhesion between cellulose fibers and matrix.

Kumar et al. [83] described the development and characterization of a new set of hybrid natural fiber composites. Hybrid composites were prepared using bagasse fibers of pure epoxy. Tensile testing at room temperature revealed that 3wt% of bagasse yielded maximum strength of 25.5 MPa other than 0 wt.% of bagasse. Hardness at room temperature revealed that 4wt% of bagasse composite shows a maximum 67HRB compared to other compositions. The reason may be the natural fiber is distributed and dispersed uniformly across the epoxy. Cerqueira et al. [31] evaluated the effect of chemical modification on mechanical properties of SCB fiber/PP composites. Fibers were pretreated. These fibers were mixed with PP. The mechanical properties were evaluated by tensile, 3-point bending,

and impact tests. In addition, fracture analysis via SEM was performed. Results showed that the tensile, flexural, and impact strength of the composites was improved in comparison to the polymer pure. Simão et al. [84] studied the highly filled composites of PP and sugarcane bagasse fiber with and without alkali treatment. They investigated the thermal and mechanical behavior of these composites by thermogravimetry (TGA), flexural tests, impact tests, and scanning electron microscopy. The results revealed that the alkali treatment modified the fiber surface as well as the chemical composition. The impact test results showed the good potential of the coupling agent as the impact strength was increased. On the other hand, flexural modulus and flexural strength did not achieve the values for the pure PP, suggestive of poor stress transfer. Results indicated that the alkali treatment did not significantly change the fiber thermal resistance.

Samariha et al. [85] examined the feasibility of using bagasse flour for producing natural fiber-plastic composites based on PP. For this purpose, the bagasse flour was mixed with PP and MAPP coupling agent. They conducted the tensile strength and impact resistance tests according to the ASTM standard. The results showed that the tensile properties improved, but the impact strength decreased with the increase in the bagasse fiber loading from 25 to 45%. The composites treated with MAPP exhibited enhanced mechanical properties, indicating an efficient fiber-matrix adhesion. Adhikary et al. [86] investigated the stability, mechanical properties, and the microstructure of wood-plastic composites, which were made using either recycled or virgin HDPE with wood flour filler. The tensile and flexural properties of the composites based on recycled HDPE were equivalent to those based on virgin HDPE. Adding MAPP by 3–5 wt.% in the composite formulation significantly improved stability and mechanical properties. It was found that microstructure analysis of the fractured surfaces of MAPP modified composites confirmed improved interfacial bonding. Results also indicated that the dimensional stability and strength properties of the composites could be improved by increasing the polymer content or by addition of coupling agent. This project has shown that the composites treated with coupling agents will be desirable as building materials due to their improved stability and strength properties. Suradi et al. [13] produced Composites with treated and untreated lignocelluloses (oil palm empty fruit bunch) fibers using up to 45% fiber with polypropylene matrix using injection molding. MAPP was used as a coupling agent in the formulation to improve interfacial bonding. Properties of composites were evaluated using tensile testing, flexural testing, impact testing, SEM, and FTIR. The tensile, flexural, and impact properties were found to be improved with alkaline peroxide treated fiber composites compared to untreated fiber composites. The addition of coupling agent (MAPP) was also found to provide improved properties of composites.

Conclusion

Natural fiber reinforced polymer composites have beneficial properties such as low density, less expensive, and reduced solidity when compared to synthetic composite products, thus providing advantages for utilization in commercial applications (automotive industry, buildings, and constructions). Using natural fibers as reinforcement for polymeric composites introduces positive effect on the mechanical behavior of polymers. As shown in this review the efforts of researchers in studying the rheological and thermal properties, chemical resistance, and mechanical characteristics of polymers reinforced with several natural fibers were discussed. Additionally, the

effect of ultraviolet radiation on the morphology of the composites and, the influence of adding coupling agents on the properties of the natural fiber composites were discussed. The following conclusions can be drawn:

[1] The results showed that the MFI decreased with increasing in natural fiber content (wt.%). The alkali treatment and the addition coupling agent enhanced the flowability of biocomposites and increased the MFI values of biocomposites.

[2] It was found from the results of TGA analysis that the thermal stability of the composites decreased with the addition of the natural fiber into the matrix. The addition of coupling agent showed a slight increase in the degradation temperature of biocomposites.

[3] The chemical resistance to various solutions decreases with increasing the natural fiber content.

[4] The tensile strength of the composites reinforced with natural fiber in most studies increases by increasing the fiber content compared to polymeric matrix. The addition of coupling agent to the composites showed the greatest improvement in the tensile strength and young's modulus of the composites.

[5] It was also found that the flexural strength and Young's modulus results demonstrated remarkable improvement for the treated fiber, rather than the weight of fiber content. It was maybe due to the better interfacial adhesion and better fibrillation of these fibers that contributed effectively to the enhancement in the flexural properties. The coupling agent improved interfacial bonding between the fiber and the matrix and improved the flexural strength.

[6] The UV degradation normally starts at the specimen outer surface due to the interaction between the photons from UV radiation and matrix molecules on the exposed surface causing the photo-oxidation of the outer layers, which can come in direct contact with the atmospheric oxygen and proceeds rapidly, mainly through radical chain oxidation reactions. While, the inner layers, which cannot under usual circumstances be reached by the atmospheric oxygen, degrade more slowly through photo-reactions of peroxy radicals or reaction of radical pairs.

[7] During accelerated weathering, as natural fiber increase composites, mechanical properties reduced. The surfaces of samples exposed to the accelerated weathering environment were observed to change in the form of color fading and deposition of white chalky material.

[8] The physical and mechanical properties of natural fiber reinforced polymeric composites can be further enhanced through the chemical treatment, and addition of coupling agents.

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The authors are willing to share the data and material according to relevant needs.

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